METHOD FOR PLASMA ETCHING WITH PULSED SUBSTRATE ELECTRODE POWER

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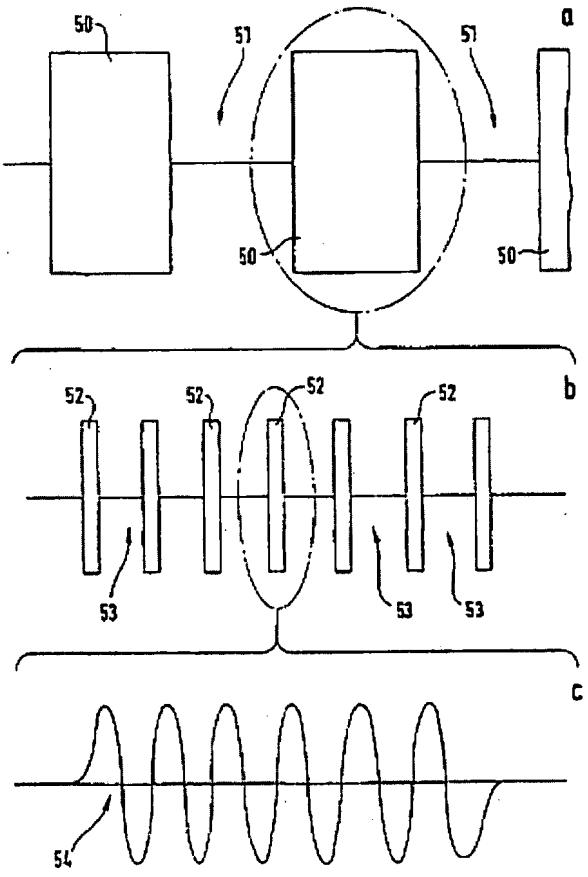
Abstract of **DE19957169**

A method for etching structures in an etching substrate (18), in particular in a silicon body (18) by means of a plasma (14) with a lateral extent, which is exactly defined by means of an etching mask, is disclosed. A high frequency pulsed high frequency power is coupled with the etching substrate (18) by means of an, at least temporarily applied, high frequency alternating voltage. Said coupled high frequency pulsed high frequency power is furthermore modulated with a low frequency and, in particular, cycled. Said disclosed method opens a wide process window, for the variation of etching parameters in the plasma etching process as carried out and is particularly suitable for the etching of structures in silicon, with high mask selectivity and high etching rates, with simultaneously minimised charging effects, in particular with regard to pocket formation on dielectric boundary surfaces.



Result Page

The invention concerns a procedure for corroding structures in a corroding body by means of a plasma, after the kind of the principal claim.

State of the art

Anisotropic plasma etching techniques are for example from DE 197 06 682 A1 or DE 42 41 045 C2 well-known, in which over a high-density source of plasma a plasma from neutral radicals and electrically charged particles is produced in each case, those by a bias voltage supply to a substrate electrode, which carries the too prozessierenden wafer, to be accelerated. By the preferred direction of the incident ions thereby an arranged etching process comes off.

When bias voltage supply, which produces the electrical tension for the acceleration of the ions from the plasma for the substrate electrode, far usually high frequency generators with a carrier frequency of 13.56 MHz used. The high frequency generator is adapted in each case by a process card network (?match box?) to the impedance of the substrate electrode and the plasma, which are located in contact with the substrate electrode.

In consideration of a good mask selectivity, which is the relationship of the silicon etching rate to the etching rate of the masking layer, is further already well-known to select the high frequency achievement at the substrate electrode relatively low in order to keep the ion-supported mask erosion as small as possible. Usual power ratings lie between 5 Watts and 20 Watts, so that the energy of the ions breaking in on the substrate surface amounts to typically some 10 eV.

Such low ion energies are regarding the mask selectivity favourable, them lead however also in addition that the incident ions in their direction strew relatively strongly and can partly from desired senkrechten the idea deviate or be easily diverted, D. h. their Direktionalität is small. Such deviations of the Direktionalität of the incident ions correlate then with less favourable profile control of the produced corroding profiles. Under the aspect of the Direktionalität of the ion stream therefore a high ion acceleration, thus high ion energy, would be desirable, which collided however with the demanded mask selectivity.

It continues to come with the employment of high-density plasmas with low-energy ion effect on a substrate with the impact a corroding stop from dielectrics (buried oxides, films of varnish etc.) often to loading effects at the boundary layer silicon dielectric. From this one calls resulting profile disturbances in silicon bag formation (?Notching?) at the dielectric interface.

At the same time also the danger of the so-called ?grass formation? grows on the corroding reason, of D with removing ion energy. h. the process window for a safe etching process without grass formation is limited. By ?grass formation? one understands thereby an uneven corrosion of the corroding reason under training of a multiplicity of closely neighbouring points, which take the form of a lawn.

In the registrations DE 199 33 842,6 and DE 199 19 832,2 for the solution of these problems, the high frequency alternating voltage, those was already suggested for substrate bias production, D. h. for the production of the substrate electrode achievement which can be linked into the substrate which can be corroded, to pulse and the ion energy is used during the high frequency impulses more highly to select at the same time than with a continuous-wave operation.

With this Pulsbetrieb it is however observed that an effective suppression of the bag formation is only reached at relatively long Pausenzeiten the high frequency impulses put on from 0,1 ms to 1 ms between. If those are shortened impulse tracing under 0,1 ms, bag formation arises increasingly again, which cannot be suppressed also by an increase of the pulse peak achievement and a corresponding Verkürzung of the pulse time any longer.

For long Pausenzeiten of 0,1 ms to 1 ms besides the process window for a safe process, D narrows itself. h. a grass-free corroding reason, with Verkürzung of the pulse time with appropriate increase of the pulse peak achievement, D. h. the etching process will ever bag-more stable, the suppression of a grass-free corroding reason becomes however ever smaller. The demand of a ?bag-stable? process contradicts thus so far a ?grass-stable? process.

By the process window one understands thereby the process parameter ranges, in particular regarding process pressure, suitable for the execution in the described way of a safe etching process, substrate electrode achievement, plasma achievement and gas flows as well as if necessary the cycle times for alternating corroding and passivating cycles.

Altogether the applicable high frequency pulse peak achievements and thus the ion energies, thus the Direktionalität of the ion idea, are limited with the well-known procedures thus under the boundary conditions of a sufficient suppression of the ?bag formation? and a ?grass-free? corroding reason, so that so far an unwanted restricting of the process window, D. h. the usable process parameters, occurs.

Particularly disturbing this restricting the process window affects itself due to the grass formation if high rate etching processes are to be accomplished, since thereby the range of the permissible process pressures is upward limited. On

the other hand are favourable straight high pressures, high gas flows and high plasma achievements at the inductive source for the reaching of high etching rates.

Advantage of the invention

The plasma etching technique according to invention has the advantage in relation to the state of the art that thereby the pulse and Pausenzeiten of the linked, high frequency pulsed high frequency achievement clearly to be shortened to be able and thus a Pulsbetrieb with high repetition rate is representable in 100 kHz the range.

According to the pulse break relationship far knows favourably now also the pulse peak achievement proportionally to it in reverse increased and/or with this high repetition frequency. are high-scaled.

At the same time apart from the effective suppression of the bag formation (Notching effects) a very stable and durable process is reached, which does not bend during variation of the process parameters within a far process window to the formation of ?grass? at the corroding reason.

Further now very high high frequency maximum performances can at according to short pulse duration, D with the procedure according to invention. h. according to small pulse break and/or. Impulse period relationship, to be used. Thus an accordingly high ion energy of typically 50 results favourably eV until 1000 eV, which is connected with a very good
▲ top Direktionalität of the ion idea.

One uses that with the employment of short pulses with high repeating rate temporal averaging of the power ratings takes place by means of a close consequence from short time pulses, from which each particular only a relatively small energy entry on the corroding body explains. This leads altogether to a high process stability.

Contrary to relatively long pulses with relatively long tracing, with which the energy is not already so large in a single pulse that during a single pulse breakdown effects in the electrode plasma reciprocal effect arise, with the procedure according to invention favourably far any more observed that with Verkürzung that pulse lasting and appropriate increase of the pulse peak achievement an increase of the middle registered achievement needed with the corrosion into the substrate electrode and/or. the corroding body is necessary. Rather now scales period relationship and necessary pulse peak achievement quite well in reverse proportionally.

Altogether by high frequency pulsing of the high frequency achievement pulses breakdown effects in the plasma substrate electrode reciprocal effect are effectively suppressed, so that with given frequency of the high frequency generator, for example 13.56 MHz, and given, middle, into which corroding body of linked high frequency achievement the ion energy can be selected and according to the middle ion stream on the corroding body freely.

If one with P the middle high frequency achievement, which is to be regarded constant as a certain etching process, with p the pulse maximum performance, linked into the corroding body, and/or. Amplitude of the high frequency achievement in a pulse, with D the pulse period relationship (?Duty Cycle?), with u the ion accelerating voltage according to the energy ions, with i the pulsed ion stream, and with I the temporal average value of the ion stream, of the hitting the corroding body, designation, applies therefore with the process according to invention now:

EMI7.1

Assumed that plasma impedance X with the linked high frequency achievement changes for only little, thus the Ohm' law approach applies. In practice plasma impedance X with increase of the linked high frequency achievement will even still increase due to saturation effects of the ion stream and limited, available ion densities in the plasma and the described effect still will thus strengthen.

Altogether the procedure according to invention leads thus favourably to the fact that itself with reduced period relationship D (or similar to a reduced pulse tracing relationship) and according to high-scaled pulse peak achievement p, D. h. constant middle achievement P, to which energy u ions of the hitting the wafer applies:

EMI7.2
during the middle river I itself in accordance with I PROPORTIONAL 2ROOT D holds back.

Thus now Cycle parameter? D can be selected with same achievement entry freely over the ?Duty whether a high ion energy with according to small middle ion stream or a low ion energy with according to high middle ion stream is to be stopped. One received thus an additional degree of freedom of the etching process according to invention, which corresponds to an adjustableness of the plasma impedance, and which in addition can in its effect be used, the process window, for example for high rate etching processes to extend.

According to invention procedures has far substantial advantage that apart from a high frequency achievement high frequency pulsed, which serves process stability in a far process window and the suppression of over the characteristics of ion energy and middle ion stream controllable grass formation, and which leads also to high etching rates, by means of which additional, low-frequency modulation of the high frequency achievement also the bag formation at dielectric boundary surfaces, high frequency pulsed, effectively can be suppressed.

This low-frequency modulation is based on the realization that relative to a dismantling of loading effects at these dielectric boundary surfaces long times of usually more than 0.5 ms are necessary. From this a frequency range for the low-frequency modulation from 10 cycles per second to 10000 cycles per second results, preferably from 50 cycles per second to 1000 cycles per second.

The procedure according to invention is suitable thus particularly favourably for a bag-stable high rate etching process with increased process pressure of for example 20 mu bar to 300 mu bar and high plasma achievement of up to 5000 Watts.

Favourable training further of the invention result from the measures specified in the Unteransprüchen.

Like that it is particularly favourable that also with a small pulse break relationship of for example 1: 9 to 1: 19 and

according to high pulse maximum performances of the linked high frequency achievement outputs of 100 Watts up to 200 Watts a broad process window regarding the grass education danger remains received.

It continues to be favourable that usual high frequency generators can be operated in such a way that a high frequency pulsing of the linked high frequency achievement is possible in the form of rectangle pulses, whereby the rise times of the clock flanks exhibit less than 0.3 mu s with a carrier frequency of 13.56 MHz. Thus the procedure according to invention can be accomplished favourably with commercially available generators, which must be modified if necessary only slightly.

A so short rise time of the clock flanks is necessary, in order to be able to accomplish at all a high frequency achievement pulsing with a frequency from 10 kHz to 500 kHz.

For the pulse peak achievement, D. h. the amplitude of the high frequency achievement during a linked high frequency achievement pulse can be used far favourably outputs of 30 Watts up to 1200 Watts.

For the production of the low-frequency modulation of the high frequency achievement high frequency pulsed stand far favourably two alternative, possibilities which can be realized in each case simply for order.

On the one hand, the already high frequency clocked high frequency generator, for example over its gate entrance, integrated in the generator unit, can additionally directly with a low-frequency clocking be switched on and off.

On the other hand exists also the possibility, one into the generator unit integrated high frequency master clock, which modulates the actual carrier signal of the high frequency generator, and thus high frequency pulsing of the high frequency achievement causes to steer with a low-frequency master clock. In this way the high frequency master clock is expenditure-input and output low-frequency, which is passed according to also to the linked high frequency achievement pulses.

Designs

The invention is more near described on the basis the designs and in the following description. The Fig. 1a up to 1K describe a pulsing of the high frequency achievement linked into the corroding body, the Fig. a principle sketch of a corroding plant to the execution of the etching technique, and the Fig points 2. 3a and 3b describe two alternative execution forms of the generator unit.

Remark examples

The Fig. one points 2 in principle from DE 42 41 045 C2 or DE 197 06 682 A1 well-known plasma corroding plant 5 to the execution of an anisotropic plasma etching technique. In addition a substrate electrode 12 intended with a corroding body arranged on it 18 is in a corroding chamber 10, which is in the described example a silicon wafer. The substrate electrode 12 with a generator unit 30 continues to stand electrically in connection. In addition a resonator 20 is intended, with which in the corroding chamber 10 within the range of a Surfatrons 16 a plasma 14 is produced. The described remark example is not limited however to a such installation configuration. In particular for it also an actually well-known ICP Plasmaquelle (?Inductively coup LED plasma?) or ECR Plasmaquelle (?Electron Cyclotron Resonance? is suitable).

Substantial it is always only that a high-density source of plasma produces a plasma 14, which consists of neutral radicals and electrically charged particles (ions), whereby the ions by one into the substrate electrode 12 and/or. over it into the corroding body 18 linked high frequency achievement perpendicularly to the substrate electrode 12 to be accelerated, which carries the too prozessierenden corroding body 18, and there approximately to hit, so that by the preferred direction of the incident ions an arranged etching process comes.

Without further details of the corroding plant 5 actually well-known with exception of the execution according to invention of the generator unit 30 one does, since this admits to the specialist is.

The generator unit 30 points a commercially available high frequency generator 33, a high frequency master clock 32, a low frequency master clock 31 and a so-called ?match box? 34, D. h. a process card network, up.

The match box 34 serves thereby in well-known way for which high frequency generator 33 to the impedance of the substrate electrode 12 and the plasma 14, which are located in contact with the substrate electrode 12 to adapt.

In order to ensure a good mask selectivity (relationship of the etching rate of the corroding body 18 to the etching rate of a masking layer applied on it), over the generator unit 30 in the temporal means a high frequency achievement is linked from 1 Watt to 30 Watts into the substrate electrode 12.

In order to produce into the substrate electrode 12 and over it into the corroding body 18 linked, high frequency pulsed the high frequency achievement, it is first intended that the high frequency generator 33 in the generator unit 30 prefers a high frequency carrier signal 54 with a frequency of 13.56 MHz and an achievement produced by for example 400 Watts. In place of the frequency of the carrier signal of 13.56 MHz however likewise frequencies from 1 MHz to 50 MHz are applicable. The achievement of the high frequency generator 33 can amount to further also between 30 Watts up to 1200 Watts. Outputs of 50 Watts up to 500 Watts are preferential.

In a first remark example of the invention is in accordance with Fig. 3a further intended that the generator unit exhibits 30 beside the high frequency generator 33 and the match box 34 an actually well-known high frequency master clock 32, which steers the high frequency generator 33 in such a manner that this produces a high frequency achievement high frequency pulsed. This becomes on the basis the Fig. 1K and 1b describe.

In detail is in Fig. 1K the high frequency carrier signal 54 of the high frequency generator 33 with a frequency represented by for example 13.56 MHz and a Spannungsamplitude, which correspond to an achievement of for example 400 Watts. From pulsing the high frequency generator 33 with the high frequency master clock 32 result then in accordance with Fig. 1b high frequency pulses 52, after which a high frequency pulse break 53 follows in each case. Clocking the carrier signal 54 of the high frequency generator 33 effected via the high frequency master clock 32 with a frequency from 10 kHz to 500 kHz, prefers from 50 kHz to 200 kHz. The pulse break relationship of the high frequency

achievement in accordance with Fig, high frequency pulsed. 1b lies between 1: 1 and 1: 100. Particularly preferentially it lies between 1: 2 and 1: 19.

First, on the basis of the produced achievement of the high frequency generator 30, a high frequency achievement averaged temporally over pulses and tracing is produced by the selected pulse break relationship of the high frequency achievement high frequency pulsed from 1 Watt to 100 Watts.

The generator unit 30 continues to point in accordance with Fig. 3a an actually well-known low frequency master clock 31 up, that the high frequency master clock 32 periodically switches on and off and/or. clocks. In this way the high frequency achievement high frequency pulsed becomes in accordance with Fig. 1b additionally low-frequency modulates. In detail in addition the low frequency master clock 31 clocks the high frequency master clock 32 with a frequency from 10 cycles per second to 10000 cycles per second. Frequencies from 50 cycles per second to 1000 cycles per second are preferential.

Altogether becomes thus by low-frequency clocking and/or. low-frequency modulation with the help of the low frequency master clock 31 periodic switching and switching on of the linked, pulsed high frequency achievement off on into the substrate electrode 12 and over it into the corroding body 18 causes. The pulse break relationship of low-frequency clocking of the low frequency master clock 31 in accordance with Fig. 1a, D. h. the relationship of low-frequency pulses 50 and low-frequency pulse tracing 51, is thereby between 4: 1 and 1: 4. As particularly favourable turned out, if the pulse break relationship of low-frequency clocking between 1: 2 and 2: 1, for example with 1: 1 lies.

By low-frequency clocking of the high frequency achievement high frequency pulsed in accordance with Fig. 1b becomes the high frequency achievement linked finally into the corroding body 18 according to the respective pulse break relationship (Fig. 1a) reduced, so that into the corroding body 18 a typical high frequency achievement between 1 Watt and 30 Watts is finally linked.

The high frequency pulses 52 in accordance with Fig. 1b have in all other respects regarding the envelopes preferentially at least approach the form of rectangle pulses, whereby the rise time of the clock flanks of the rectangle pulses amounts to less than 0.3 mu s.

In all other respects it is easily possible to connect the low frequency giver 31 with a not represented plant control and by it in the course of the accomplished etching process the middle to steer into the corroding body 18 linked high frequency achievement. In addition the pulse break relationship particularly offers itself to low-frequency clocking. The pulse break relationship of the high frequency achievement in accordance with Fig, high frequency pulsed. 1b is particularly suitable for the process optimization regarding the grass formation already described. Exactly the same it is naturally possible to record and regulate for the controlling of the middle achievement the pulse peak achievement of the generator the pulse break relationship of low-frequency clocking.

The Fig. 3b describes one to Fig. 3a alternative execution form of the generator unit 30 for the production of a high frequency achievement high frequency pulsed, which is low-frequency modulated. In addition becomes in accordance with Fig. 3b the high frequency generator 33 first similar to the Fig. 3a by means of a high frequency master clock 32 high frequency clocked, so that it a high frequency achievement in accordance with Fig, high frequency pulsed. 1b produces. In contrast to Fig. 3a is in Fig. 3b however intended that the low frequency master clock 31 does not steer the high frequency master clock 32, but directly with the high frequency generator 33 connected is and these clocks additionally directly. A circuit in accordance with Fig. 3b can be realized particularly simply by the fact that one attaches the low frequency master clock 31 high frequency generators 33 usual to the gate entrance, which are additionally high frequency clocked for example over an internal master clock or the external master clock 32. The remaining processing parameters at the time of the execution of the etching technique in accordance with Fig. 3b according to the procedure in accordance with Fig. 3a and/or. the Fig. 1a up to 1K.

The Fig. 1a up to 1K describe in summary in the overview again, high frequency pulsed the high frequency achievement provided linked into the corroding body 18 with a low-frequency modulation. In addition one goes first from Fig. 1K, D. h. the high frequency carrier signal 54 of the high frequency generator 33 out. This carrier signal 54 becomes by the high frequency master clock 32 in accordance with Fig. 1b in high frequency pulses 52 and high frequency pulse tracing 53 partitions. The high frequency pulses 52 have thereby ideal-prove at least to approach the form of rectangle pulses (envelope) and by the carrier signal 54 are formed. The Fig. 1a describes then as with the help of the low frequency master clock 31 a low-frequency clocking and/or. Modulation, high frequency pulsed of the high frequency achievement linked into the corroding body 18 is made. In addition a multiplicity of high frequency pulses becomes 52 and/or. high frequency pulse tracing 53 combined into low-frequency pulses 50, which in each case then a low-frequency pulse break 51 follows. The low-frequency pulses 50 exhibit a rectangle pulse form preferentially likewise as envelope. The signal in accordance with Fig. 1a is then linked over the substrate electrode 12 into the corroding body 18 as high frequency achievement.

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Result Page

1. Procedure for corroding structures in a corroding body (18), in particular characterized by laterally recesses in a silicon body, by means of a plasma (14), defined accurately with an etch resist, whereby into the corroding body (18) over a at least temporarily fitting high frequency alternating voltage at least temporarily a high frequency achievement high frequency pulsed one links, by the fact that the linked, high frequency pulsed high frequency achievement is low-frequency modulated.

2. Procedure according to requirement 1, marked by it that the high frequency alternating voltage is made available by means of a high frequency generator (33), the one high frequency carrier signal (54) produces.

3. Procedure according to requirement 1, by the fact characterized that the high frequency achievement with a frequency from 10 kHz to 500 kHz, in particular 50 kHz to 200 kHz, high frequency pulsed, one pulses.

4. Procedure after at least one of the preceding requirements, by the fact characterized that the high frequency carrier signal (54) exhibits a frequency from 1 MHz to 50 MHz, in particular 13.56 MHz.

5. Procedure after at least one of the preceding requirements, by the fact characterized that the high frequency generator (33) produces a high frequency achievement with an amplitude from 30 Watts to 1200 Watts, in particular for 50 Watts up to 500 Watts.

6. Procedure after at least one of the preceding requirements, by the fact characterized that the high frequency achievement high frequency pulsed is linked in the form of rectangle pulses (52).

7. Procedure after at least one of the preceding requirements, by the fact characterized that the rectangle pulses (52) exhibit a rise time of the clock flanks of the rectangle pulses (52) of less than 0.3 mu s.

8. Procedure after at least one of the preceding requirements, by the fact characterized that pulse break the relationship (52, 53) of the high frequency achievement between 1, high frequency pulsed: 1 and 1: 100, in particular between 1: 2 and 1: , is appropriate for 19.

9. Procedure after at least one of the preceding requirements, by the fact characterized that the consequence of the . achievement pulses (52) and pulse tracing (53), high frequency pulsed, corresponds to a middle high frequency achievement from 1 Watt to 100 Watts.

10. Procedure after at least one of the preceding requirements, by the fact characterized that the linked, high frequency pulsed high frequency achievement with a low-frequency clocking (50, 51) is modulated periodically.

11. Procedure after at least one of the preceding requirements, by the fact characterized that low-frequency clocking (50, 51) or the low-frequency modulation (50, 51) with a frequency takes place from 10 cycles per second to 10000 cycles per second, in particular 50 cycles per second up to 1000 cycles per second.

▲ top 12. Procedure after at least one of the preceding requirements, by the fact characterized that low-frequency clocking (50, 51) or the low-frequency modulation (50, 51) causes a periodic switching and switching on of the linked pulsed high frequency achievement off on.

13. Procedure after at least one of the preceding requirements, by the fact characterized that pulse break the relationship of low-frequency clocking (50, 51) between 4: 1 and 1: 4, in particular 1: 2 and 2: 1, lies.

14. Procedure after at least one of the preceding requirements, by the fact characterized that the high frequency achievement linked in the temporal means into the corroding body (18) lies between 1 Watt and 30 Watts.

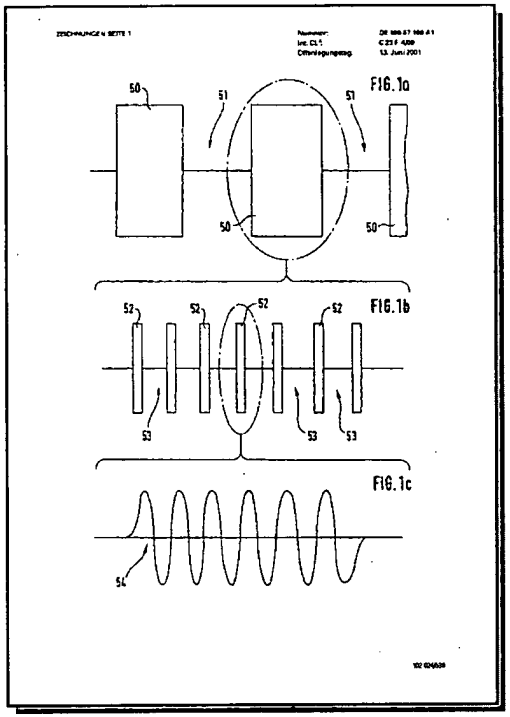
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FIG. 1a
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FIG. 1b
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FIG. 1c

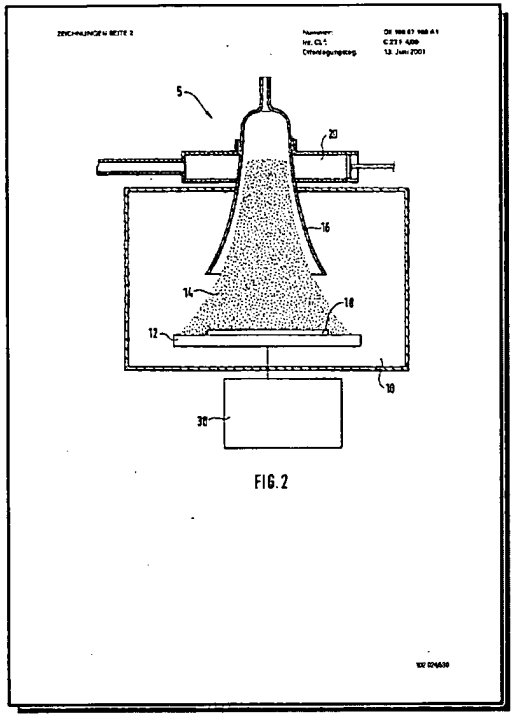
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FIG. 2

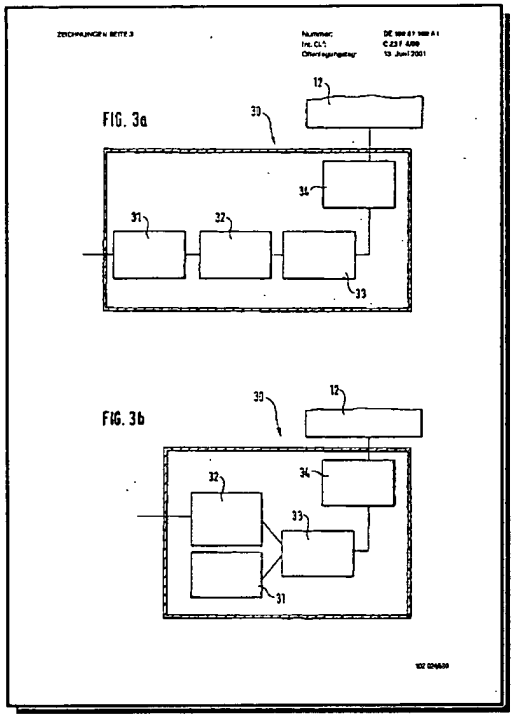
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FIG. 3a
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FIG. 3b

METHOD FOR PLASMA ETCHING WITH PULSED SUBSTRATE ELECTRODE POWER

Legal status (INPADOC) of **DE19957169**

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